

Orthogonal Frequency-Division Multiplexing-Based Cooperative Spectrum Sensing for Cognitive Radio Networks

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Abstract

The detection of transmitted data collusion among sensing nodes needs to be resolved at data link layer. It takes a lot algorithm calculation effort and time constraint. A new method to sense the performance of cognitive radio (CR) by avoiding interference based on new master node (MN) algorithm. Interference could be reduced significantly by using only PHY (physical) information of the cognitive radio network. It saves a lot computational on above layer and detect the collusion of transmitted data as early as possible. By using a novel MN algorithm at PHY layer, it reduces the cost of computation and time to detect and avoid collusion of transmitted data.

Keywords: Cooperative sensing, Subcarrier mapping, Interference, Spectrum Exchange Information, PHY layer

1. Introduction

One of the most important findings from the measurements reported in [1] is that a large portion of the radio spectrum is not in use for significant periods of time in certain areas. Thus, there are a lot of spectrum holes, which are defined as a set of frequency bands assigned (licensed) to a user (primary user), but, at a particular time and specific geographic location, not being utilized by that user [2]. On the other hand, the report also pointed out that most of the unlicensed spectra are heavily accessed by users and have high spectrum utilization thanks to the possibility of open access with relaxed regulations.

CR has been proposed as a means to achieve such dynamics. The cognitive-radio devices have two important functionalities: spectrum sensing and adaptation. An unlicensed user first senses the spectrum environment in order to learn the frequency spectra unoccupied by licensed users. Once such a spectrum hole is found, the unlicensed user adapts its transmission power, frequency band, modulation, etc., so that it minimizes the interference to the licensed users. Even after starting the transmission, the secondary terminal should be able to detect or predict the appearance of a licensed user so that it makes the spectrum available for the licensed user.

One of the main components of CR is spectrum sensing, by sensing it adapting to the environment. Spectrum sensing techniques is featuring detection and signal specific aspect detection scheme. Sensing method should decide whether is depending of SNR, minimal sensing time or scanning of spectral bandwidth. In other hand, CR must be able to demonstrate use with minimal impairment to the licensed user. If a CR does not see energy in a specific band can it assume that the licensed user is not present? The answer depends on what level of energy it can reliably senses. To overcome this problem cooperative spectrum sensing by a group of collaborating sensing has been proposed to exploit multi-user diversity in the sensing process [3], [4], [5].

Cooperative spectrum sensing method requires information exchange to save the limited channels and bands. It is necessary to keep the primary system remains in the sensing node (SN) sight. Some exchange method [6, 7] proved that the exchange signals will need a few bits of symbols. However, almost all of the method assumed that the information is perfectly exchange between nodes.

The organization of the paper is as follows. OFDM based spectrum sensing cognitive radio is discussed in section I and II respectively. Section III deals with analysis work in the field

of OFDM based cooperative spectrum sensing, the sections IV and V describe the working of the new subcarrier OFDM mapping system performance and the algorithm. The simulation results are summarized in section VI. Section VII concludes with the scope of future work in this relation.

2. OFDM Based Cooperative Spectrum Sensing for Cognitive Radio Networks

Nowadays, OFDM techniques are adopted by many existing technology, there have been a variety of spectrum sensing schemes at the physical layer for cognitive radio systems. Recent research on spectrum sensing focuses on more practical sensing techniques utilizing various characteristics in transmitted signals, such as cyclic prefix-based detection for the OFDM signal. [8] presented sensing methods based on both power detector and waveform detector. [9] proposed a method based on exploiting the cyclostationary characteristics of the licensed user signal. However, in conventional spectrum sensing schemes, an unlicensed user is not able to sense the spectrum during data transmission period because both transmitting and receiving signals. As a result, the idle period for sensing is unavoidable. This idle period is system overhead, which causes decrease in the total throughput of the secondary user [3], [5], [6], [7].

In case of overcome the difficulty of licensed detection which occurring multipath and shadowing [10] has introduce test statistic based on soft decisions in cooperative sensing. The experimentation is building on MIMO mesh network and examines two proposed methods, single carrier and multi-carrier of OFDM. The evaluation is experiencing in cooperative sensing and non cooperative sensing. In single carrier cooperative sensing show that PD can be improved by increasing number of unlicensed users. In terms of multi-carrier cooperative sensing is consider efficient approach to ad-hoc network since the lowest SNR in users can aided by other user.

A new approach has been proposed by [11] to combating power loss over propagation distance in CR networks. OFDMA is considering overcoming the transmission loss with respect to the distance between transmission pair. Cyclic prefix length utilized to detect the licensed users in order to avoiding interfering with licensed systems. Comparing to [12], this works is done by collect the FFT size and cyclic prefix samples with sampling rate and assumed it to be one OFDM symbol. Although the FFT size is just uses only for signal classify, however the cyclic prefix is able detect the presence of licensed user and avoiding the interference.

In other hand [13] proposed spectrum sensing scheme that exploiting the cyclic prefix of an OFDM symbol for CR systems. In this case [13] evaluate with [8] works which is the scheme is able to transmit the whole cyclic prefix portion in order to avoidance performance degradation from null guard interval. In this scheme, they assumed that time-division duplexing (TDD), an unlicensed users detects the licensed user during receiving period and decides whether to transmit its data during transmitting period. They results show it improve sensing accuracy and increase system throughput compared to the conventional schemes.

In order to solve the information exchange problem in conventional cooperative spectrum sensing, [6] proposed a novel information exchange method based on mapping the information into a subcarrier signal on OFDM signal structure. In this method, information is transmitted to the CR node by mapping the sensing result of unlicensed sensing node to a subcarrier number of OFDM. In each sensing node, the signal that contains the tone signal at the selected subcarrier is transmitted to the CR node at the same time of the other sensing nodes. Therefore, the CR node can obtain all sensing information at the same time by detecting the OFDM signals from the surrounding sensing nodes. The method concluded that the received signal power can be changed and reduce the required bit information in a subcarrier exchange. Therefore, in their results, the spectrum hole of primary user are representing in selected subcarrier of CR's users.

Moreover, the generating packets in the master node by receiving of the information exchange require the bandwidth resources which are able to accommodate the traffic channel in the transmission process. This is become the drawback due to require large packet processing in the transmission bit symbols. Therefore, we have to provide large capacity dedicated channel for exchange information.

However, in the proposed subcarrier mapping information exchange method, the received power is mapping into k^{th} subcarrier number with exchange information perfectly. In

this method, the energy level of the received signal power in each sensing nodes depend on the value of k . However, if the energy level is huge then k is also high, because k represents the received power in the sensing nodes.

Moreover, sending information mapping results more frequent may causes on inter carrier interferences (ICI), therefore the subcarrier number may probable collision, or crash, or cross talk, impair or increase each other for the same of k th subcarrier number as shown in figure 1. Inter carrier interference/collision subcarrier/concatenation subcarrier among subcarrier mapping on OFDM based cooperative sensing, which each is sensing nodes have probable occupied by the same subcarrier number and the same power levels. To solve the drawback, we have to provide a large channel traffic and huge capacity of dedicated channel.

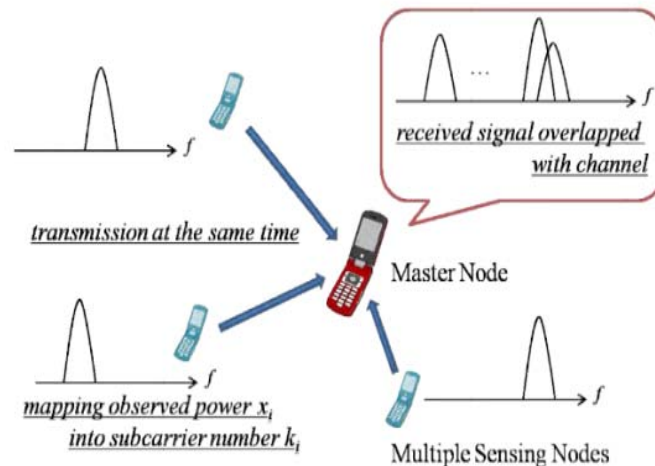


Figure 1. The received signal k subcarrier interference or overlapped on control channel

In cooperative, before transmitting any signal, the nodes should estimate the power spectral density of the radio spectrum so as to check which bands are in use and which bands are not utilized. For this requirement the nodes should use a highly sensitive receiver which can measure the observer signals in the surrounding. However, currently, there exists no practical way for a cognitive radio to measure or estimate the interference at nearby licensed receivers. This becomes the challenge for the research that focuses in cooperative spectrum sensing.

Each SN users, assuming that can detected the presence of the PU signal who can interference or can be interference with. Nowadays, there's no simple solution to the problem of locating PU. In conventional CR networks, interference occurred when the spectrum opportunities is identified when some pair of SU can transmit unsuccessfully due to harmfully interferer to the spectrum holes of the PU. Although, the presence of the primary signal either presence or no, therefore, SN users should be able to identify where and when it's possible to transmit according to the interference threshold at the PU system by given the policy managements.

Since the interference harmfully interferer to the sensing nodes (SN's), the radius is minimum distance among PU transmitter and SN receivers to avoid the interference. When the SN's receivers are out of this radius, the interference experience is the SN's node is allowed. The fact leads that this radius depends on the transmitted power by PU transmitter and interference margin of the primary receiver (SN).

3. Proposed System Design

In this works, distributed cooperative sensing is experience which able to shares, collects, and combined the sensing data utilize energy detection techniques. The energy detector method detects unknown signals embedded by comparing the observed received signal power level with a threshold. The statistical decisions are dividing into two hypotheses, H_0

and H_1 where I is the node index number, I is the number of all sensing nodes and x is the test statistic of the cooperative sensing [10].

$$H_0: x = \frac{1}{NI} \sum_{i=0}^{I-1} \chi_i = \frac{1}{NI} \sum_{i=0}^{I-1} \sum_{n=0}^{N_i-1} |w_i[n]|^2 \quad (1)$$

$$H_1: x = \frac{1}{NI} \sum_{i=0}^{I-1} \chi_i = \frac{1}{NI} \sum_{i=0}^{I-1} \sum_{n=0}^{N_i-1} |A_i s_i + w_i[n]|^2 \quad (2)$$

$w_i[n]$ denotes the noise of the n th sample, N is the number of all samples. $A_i s_i$ is the amplitude of the received signal when the signal $s_i[n]$ transmitted and the channel gain is A_i . The detection function of the presence of the primary user at the fusion centre given by [10]

$$\sum_i \chi_i > \gamma \quad (3)$$

When the equation is true, the primary user is judge to be present. This threshold γ is decide to satisfy the probability of false alarm, P_{fa} , if assumed the summed signal is regarded as Gaussian as shown in [10]. Then the threshold γ is given by:

$$P_{FA} = \int P(\chi > \gamma | H_0) dx \quad (4)$$

In Figure 2, the master nodes who wants to send the secondary data requests to the surrounding unlicensed nodes to reply the sensing information. At the surrounding unlicensed nodes (SN's), when the request for sending the sensing result is received, the surrounding sensing nodes convert the received signal power of the sensed spectrum to a subcarrier number of OFDM.

The second step is response phase; the sensing nodes simultaneously transmit the tone signal at the selected subcarrier to the MN with adjusting the timing of all nodes by using the control signals included in the request packet from the master node. At the MN, these OFDM signals are simultaneously received. In this method, at least one OFDM subcarrier is required to spectrum sensing exchange. Therefore, the required number of subcarrier is less than that of the perfect soft spectrum sensing based cooperative sensing. In this method, all sensing results of the surrounding nodes can be mapped to the subcarriers and are then collected at the same time to the MN. In this step, the large power subcarrier is regarded as the information subcarrier and the subcarrier number is converted to the sensing results of each transmitted node. By using these sensing results, the soft spectrum sensing exchange based cooperative sensing can be performed.

However, In [6] a master node (MN) wants to know where the subcarriers may be used when the PU is active, meaning that no matter that frequencies are used or which number subcarriers is using by PU, MN just want to know is the PU can be detected on the channel that may be used. To detect the presence of free channels from PU, MN will use sensing node (SN) to initiate sensing the presence of PU. Here SN acts as a relay for the MN to determine the existence of an empty channel in PU.

In [6], the method of power concept only means that the subcarrier mapping determine by the power received in each SN ($k = [P]$), if SN receives the power turned into an OFDM subcarrier k , SN want to continue transmission of signals into subcarrier. If we have 512, then calculated inside the MN; it is from zero to 512, so the possibility of the subcarrier that need to sensing from the MN will be different from another SN to other SN. We can see inefficiency from that one, need this translated k to 512 and then the MN need to hear that 512 channels.

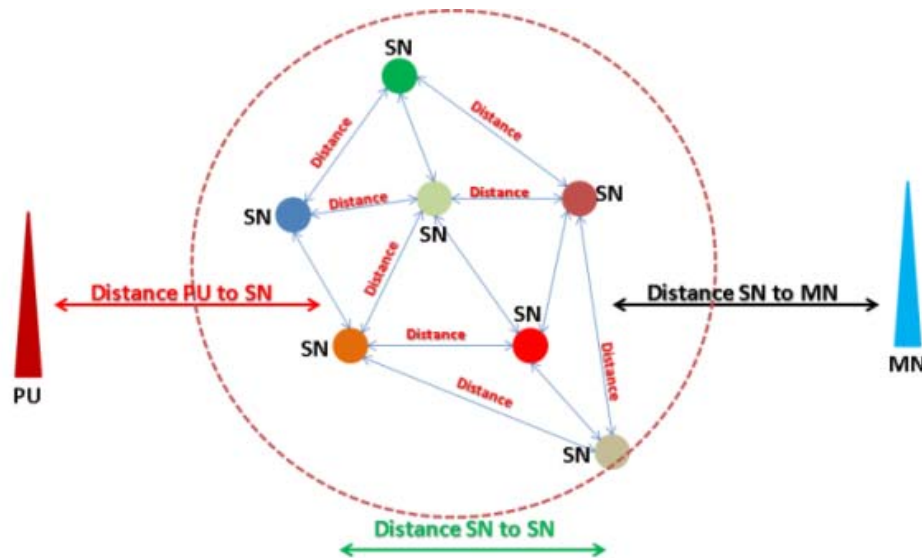


Figure 2. Sensing Demand and Response by CR Node

Means that there will a cycle for the 512 inside one second array antenna in implementation, it will be inefficiently for the N subcarriers; need to translated literally into subcarrier; there is a way control channel. The issue is common channel signaling through the OFDM signaling, if SN mobile, what about the interference, thus the problem is how do you do with the k , in [6] assumed there is no interference.

Thus, based on the previous method shows that the k subcarrier mapping is [6] we obtain that:

1. Subcarrier mapping of k will depend on the parameters mapping α , where alpha is already predetermine.
2. If α is small (< 5), the selected subcarrier is also small, but the probability of each subcarrier SN has the same number k is large, because the value of subcarrier k depends on the signal received by each SN.
3. If SN is within the boundary area close to, the effects of AWGN noise will not affect the power received by the SN. Assuming that the distance between the SN and relative the same, AWGN noise is the same, and then X_i received by the SN will be the same, so the probability of subcarrier mapping at the same k each SN will be the same.
4. Consequently, when the delivery of all the results are mapped to the MN then the probability of inter-carrier interference in MN be great when the information is received in the form of:
 - a. Subcarrier k have the same number
 - b. Relatively equal power for each k representing MN
5. If two or more sensing nodes transmit the sensing information by using a signal of the same subcarrier number, these signals are combined to one signal on the channel. Therefore the MN regards just one signal. Some time the amplitude of the combined signal is reduced and sometimes is increased. The average power of the combined signal is the summation of the signal received in the same subcarrier.

Moreover, in figure 3, if the result of the k between SN-1 and SN-2, exactly assume has the same MN, means that the k if inside the nearest place, there will be the same k . If the same k we need to differentiate between SN-1 and SN-2, because if from the power is the same, means there will be a ripple inside the power itself whether the leading, or lagging later on about the power ripple. Because [6] method is about the power only, so power can consist of power from PU or power from SN which that both of them not communicated. If not communication each other, there's no interference from the PU. The k do not care the interference, the k will not affected, because this domain between the PU and SN (see figure 2).

There is increase power to the selected k , but the power is in the form of noise, we focus to reduce the effect on the interference in the SN when SN inform the result, where the channel is free and may be used.

In this method, we propose that the SNR is calculated and affected by the distance. Because there is such a distance and the SNR will be reduced because of its interference power. If its SNR is reduced then power is also reduced. The problem between parameters of power, distance and interference influence each other $k = [P, D, I]$ other than old method $k = [P]$ [6]. Distance is a function of individual PU to SN, SN to SN and SN to MN, Power, P is the primary function of the SN and interference, I is a function of the SN with other SN. For $k = [P, D, I]$ everything is in sync with each other, the interplay between the variables with other variables. For example in figure 3 shows that;

$$P_{r(MN)} = P_{k_i SN_1}[D, I] + P_{k_i SN_2}[D, I] \quad (1)$$

Now if interference occurs such as figure 4, we must choose a method that can show a good performance in cognitive radio networks. We will choose the co-channel interference that occurs between the two SN is SN-1 and SN-2 for example. Interference to the signal SN-1 for example occurs if the SN-1 is in the coverage area of SN-2. We can calculate the ratio of the interference, power interference between SN-1 and SN-2, what is the probability the interference level in the SN-2 shadow areas, where the probability of co-channel interference received by the MN will depend heavily on the distance used.

Shadowing model will be used to model the communication channel. To be sure to measure the radius of the MN using the shadowing model in which to determine how the maximum distance, here we have to change first, D (m) into P (watts), then the new can determine the receive power and power transmission. Here we will also find out how the power distribution between the SN to the other SN (influence on the distance to the distance).

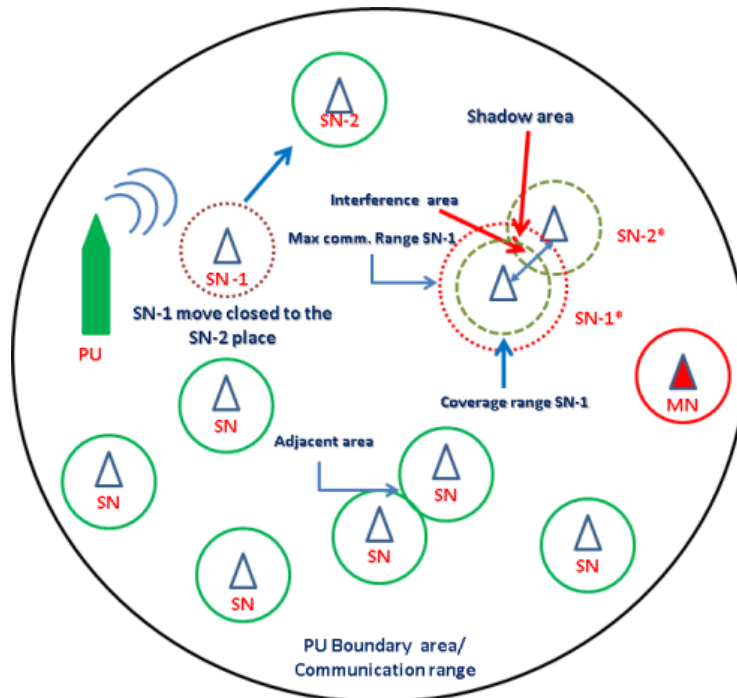


Figure 3. Interference example among SN in OFDM based cooperative spectrum sensing

Based on [6] analysis we proposed the algorithm and simulation model that introduce the power, the distance and interference parameters as the new k , such as:

1. Power transmit by PU:

$$P_{PU}(\text{power}) = SNR \text{ (dB)} = 10 \log_{10} \frac{P_{\text{Signal}}}{P_{\text{Noise}}}$$

2. The i th sensing node (SN_i) received the power of PU at channel n C_n is:

$$P_{R(SN)}(i) = P_{PU}(\text{power}) - 20 \log_{10}(4\pi^2 d_{PU}(i)) + N(0, \sigma)$$

3. SN_i , calculate its k algorithm to find its perfect k_i [6]:

$$k_i = \left\lfloor P_{PU}(\text{power})(i) * \frac{N_c}{\alpha} \right\rfloor$$

4. To avoid interference from others sensing node $SN = \{1, 2, \dots, n\}$ where ($i \in SN$) it detect the power of the channel z ($C_{nz} \rightarrow k_i$) as a results of its k ; $Z_{k \rightarrow i}$

$$X(k) \begin{cases} < N_o(\text{dB}) \rightarrow \text{Send signal to MN} \\ > N_o(\text{dB}) \rightarrow \text{Calculated new } k \end{cases}$$

$$SINR_k(\text{dB})(i) = P_{T(SN)}(i) - \log_{10} \left\{ \frac{(4\pi^2 * ((d_0(i) - d_i(i)) * 2))}{\lambda} \right\}$$

$$\begin{aligned} d_0 &= \text{reference distance of SN} & P_{T(SN)}(i) &= \text{Transmitted power of individual SN} \\ d_i &= \text{interference distance} & \lambda &= f/c = 1/\lambda; N_o = \text{Noise (dB)} \end{aligned}$$

5. If the power at channel z (C_{nz}) has bigger than N_o , SN_k will assume that channel z (C_{nz}) has been taken by other sensing node.

$$P_{Int_{SN_k}}(\text{dB}) = P_{T(SN)}(\text{dB})(i) - SINR_k(\text{dB})(i)$$

6. SN_k will iterate its k calculation based on

$$k_{new} = \left\lfloor P_{Int_{SN_k}}(\text{dB}) * \frac{N_c}{\alpha} \right\rfloor$$

$$\begin{aligned} P_{Int_{SN_k}}(\text{dB}) &= \text{Power interference of victims sensing nodes} & N_c &= \text{Number of Channels} \\ k_{New} &= \text{New } k \text{ subcarrier mapping of sensing node} & \alpha &= \text{Parameter for mapping factor} \end{aligned}$$

7. Decision on Master Node for selected subcarrier mapping of PU vacant channels [6]:

$$P_k > \gamma$$

8. Normalized to the soft sensing information [6]: $\hat{x}_j = [k + 0.5] * \left\lceil \frac{\alpha}{N_c} \right\rceil$

4. Results and Analysis

In order to investigate the scarcity of the interference problem and the effectiveness of the proposed method we perform the computer simulation and experimental test bed to verify the simulation results. But in this paper we only focus on the computer simulation evaluation.

We perform the evaluation criteria by denotes the probability detection on master node whenever perform the detection whenever incoming results presence. We investigate the detection probability of the interference on cooperative networks that using [6] Method and the proposed model. We also consider that false alarm probability combined with both influence of the [6] method and proposed model. Figure 4 shows that the probability of detection that the master node received the perfect sensing information using proposed method, on the other hand figure 5 shows that whenever interference occurred the performance of the [6] method degrades severely. Moreover, the performance of the proposed method compared with the oldest method is slightly decreased due to interference information detection and avoiding interference algorithm. Thus, the probability false alarm is better than the [6] method.

Table 1. simulation parameters [6]

OFDM Info:	Number of FFT/subcarriers = 512; Number of Channel = 11 Sampling Frequency = 20 MHz Subcarrier spacing 312.5 KHz Primary signal modulation: BPSK, single carrier
Used subcarrier index:	Tcp = 0.8e-6; Cyclic prefix duration TCP Td = 3.2e-6; Data symbol duration 3.2μs Ts = 4e-6; Total Symbol duration Ts 4μs
Master Node:	Frequency Requested = 100e2; SNR master node = 30; dB Number of Sensing Node = 100
Threshold	0 - 11.5 ; dB (Gamma)
Channel Model	AWGN, Log normal shadowing
New Subcarrier mapping parameter	208
Range of subcarrier mapping	-infinite ~20.1 [dB]
Pre-determine PFA	0.1
Received power (Xi) level of SN's	[-100 dB – (RSSI)]

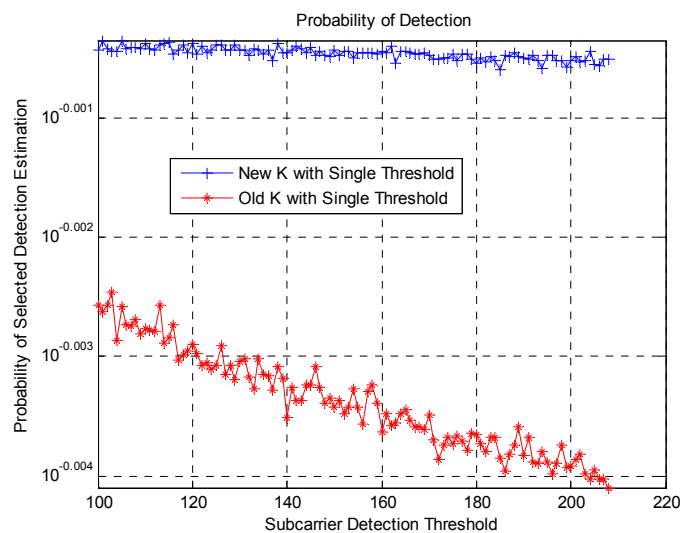


Figure 4. Probability of detection

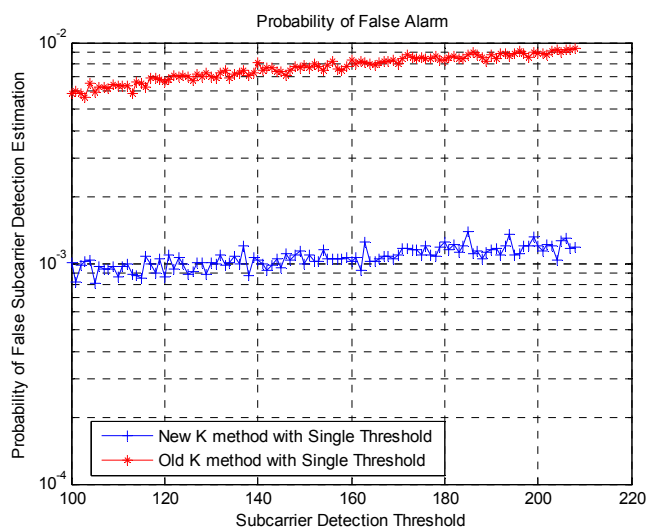


Figure 5. Probability of False Alarm

Figure 4 described that the detection probability of $k = [P, D, I]$ is able to perform better than $k = [P]$, due to the information mapping that are sending to MN more robust to diminish the limitation of interference problem among co-channel in the control channel (MN). The significant contrast has showed that using single threshold detection, the proposed method is increase the detection performances compare to previous method.

False alarm indicates that the performance of $k = [P, D, I]$ lower probability of false alarms due to mechanisms that prevent the occurrence of errors in detection due to interference, co-channel, etc. with this mechanism, the parameters can improve performance in propose to suppress error detection in OFDM subcarrier mapping. So it can be submitted as part of a system to detect the presence of PU channel is free which is better than previous methods in overcoming the interference between the SN's.

5. Conclusion

Cognitive radio (CR) has shown an attractive enormous growth which able to manage unused spectrum utilization. In cooperative sensing, they have to exchange their sensing information results to the binary information. These methods require large channel traffic and provide large capacity dedicated control. Sending exchange information mapping results more frequent may causes on inter carrier interferences (ICI). From previous model, the alpha value is fixed, so that its impact to the selective subcarrier numbers, in case if the received power, then the probability in the interval time sensing t_k of the same subcarrier number is huge. Moreover, if transmitted to the master node (MN), potentially interfere with the same subcarrier number other sensing nodes. The collisions among subcarriers will decrease the system performance drastically. In this work, in order to avoid carrier interference among the same subcarrier number we develop the method such that overcome the drawback using interference detection algorithm. Since the previous method lack information of the distance and interference factor, we propose the new subcarrier index number that involved the power, distance and interference. In these terms, we focuses investigate both in simulation and experimental study to further obtain the accurate results in research.

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